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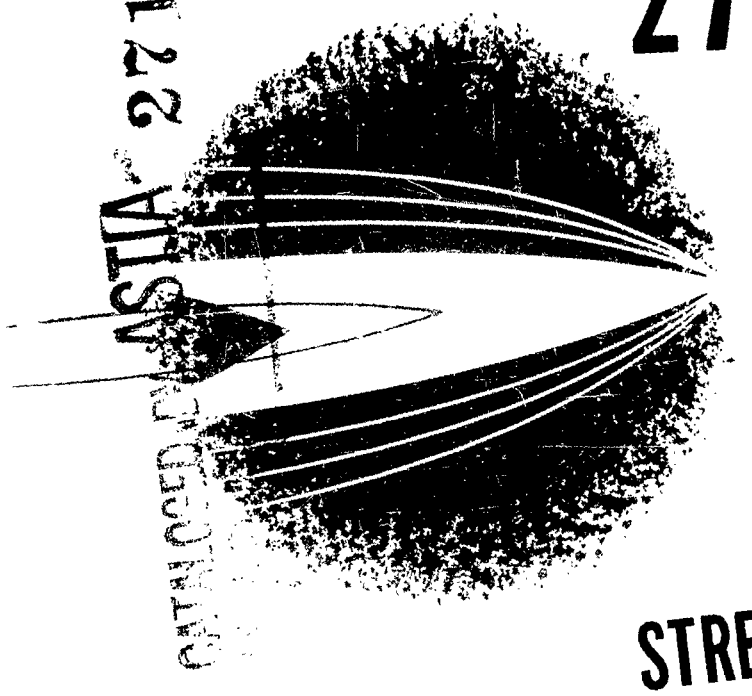

STRESS-CORROSION CRACKING OF HIGH-STRENGTH ALLOYS

Contract DA-04-495-ORD-3069

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Structural Materials Division
Aerojet-General CORPORATION
AZUSA, CALIFORNIA SACRAMENTO, CALIFORNIA
THE GENERAL TIRE
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

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INVESTIGATION OF STRESS-CORROSION CRACKING OF HIGH-STRENGTH ALLOYS

Contract DA-04-495-ORD-3069

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CONTENTS

CONTRACT FULFILLMENT STATEMENT

This is the fifth in a series of quarterly progress reports submitted in partial fulfillment of the contract.

I. OBJECTIVES

The objectives of this program are:

A. To study the susceptibility to stress-corrosion cracking of solid-rocket-motor case materials, including Vascojet 1000, Type 300M, and Ladish D6AC alloy steels, AM355, and PH 15-7 Mo stainless steels, and B120VCA titanium.

B. To study the environmental parameters, including the atmosphere both inside and outside the rocket case, that affect the rate and extent of stress corrosion.

C. To determine the effect of material parameters (composition, strength level, microstructure, surface conditions) on the stress-corrosion process.

D. To devise and evaluate techniques for preventing stress-corrosion cracking of solid-rocket-motor case materials.

II. SUMMARY

Bent-beam specimens selected from the high-strength groups of each of the alloys have accumulated over 21 weeks of exposure time in the environments of distilled and tap water. Some failures were observed with the Ladish D6AC, Type 300M, and Vascojet 1000 alloy specimens that were exposed to distilled water. U-bend specimens have undergone over 28 weeks of testing, and significant failures were noted in several of the environments. Selected bent-beam specimens, coated with solid propellant, have undergone 3 weeks of exposure without failure. Based upon the data collected so far, the Vascojet 1000 alloy steel is the least resistant to stress-corrosion cracking. A high-temperature high-humidity environment produced the most rapid stress-corrosion failures. Of the room-temperature environments, distilled water was found to produce the most rapid failures.

III. WORK PROGRESS

A. INTRODUCTION

Solid-rocket motors are often stored with propellant for long periods of time. During storage, the propellant ages and undergoes a certain amount of decomposition, the amount of which depends upon the propellant composition. The rate of decomposition increases with increased temperature. The decomposition products, usually gaseous, come in contact with the rocket-motor case. The purpose of this study is to determine what detrimental effects, if any, propellant decomposition products have upon the stress-corrosion behavior of the case material. To learn this, selected bent-beam specimens of each of the candidate alloys were bonded with a solid propellant (ANP-2639AF). After curing, half of the specimens were tested by aging at room temperature, and half were aged at 180°F.

B. BENT-BEAM TESTS

A summary of all the environmental bent-beam stress-corrosion test data compiled to date is given in Table 1. The results reflect both completed tests and tests that are currently in progress. Some bent-beam specimen failures are illustrated in Figure 1.

1. Ladish D6AC Alloy

Bent-beam specimens of Ladish D6AC steel were found to be the most susceptible to stress-corrosion cracking in the high-temperature high-humidity environment. The only room-temperature environment in which failures were observed was distilled water. For comparison, at a yield strength of 252,000 psi, the time-to-failure in the high-humidity high-temperature environment was 1 to 2 weeks; the failure time in the distilled water environment was 12 to 17 weeks.

2. Type 300M Alloy

Bent-beam specimens of Type 300M steel behaved in much the same way as the Ladish D6AC specimens. Failures were observed only in the environments of high-temperature high-humidity and of distilled water. At a yield strength of 233,000 psi, for example, failure time was less than a week in the high humidity, while the time-to-failure in the distilled water ranged from 12 to 20 weeks.

3. Vascojet 1000 Alloy

Bent-beam specimens of Vascojet 1000 steel at high strength levels failed in the environments of distilled water, tap water, and salt water. The failure times were relatively rapid when compared to the Ladish D6AC and Type 300M alloys. At a yield strength of 240,000 psi, for example, the time-to-failure in tap water was about a week, while the failure times were less than a week in the environments of distilled and salt water. No tests were conducted in the high humidity environment with this alloy.

4. AM355 Stainless Steel

Bent-beam specimens of AM355 stainless steel were exposed to the various environments for periods of time ranging from 3 to 21 weeks. No stress-corrosion cracking was observed on any of the specimens tested.

5. PH 15-7 Mo Stainless Steel

Bent-beam specimens of PH 15-7 Mo stainless steel were exposed to the various environments for periods of time ranging from 3 to 16 weeks. No stress-corrosion cracking was observed on any of the specimens tested.

6. B120VCA Titanium Alloy

The behavior of bent-beam specimens of B120VCA titanium alloy was similar to that of the stainless steel alloys. No stress-corrosion cracking was observed on any of the specimens tested after exposure to the various environments for periods of time ranging from 3 to 21 weeks. The random failures that occurred in the sodium chloride and trichloroethylene environments were attributed to faulty specimens rather than to stress-corrosion cracking.

C. U-BEND TESTS

A summary of all the environmental U-bend stress-corrosion test data compiled to date is given in Table 2. All of the U-bend tests are currently in progress; these tests represent over 28 weeks of continuous exposure. A clearer picture of the relationship of the time-to-failure to strength level and environment can be derived from the U-bend test data than was possible with the bent-beam test data. Some U-bend specimen failures are illustrated in Figure 2.

1. Ladish D6AC Alloy

Failures of U-bend specimens of Ladish D6AC steel were observed in the environments of distilled water, tap water, salt water, and trichloroethylene. At a yield strength of 252,000 psi, for example, failure times averaged 3 weeks for the distilled water and salt water environments, and 5 weeks for the tap water. One specimen failed in trichloroethylene after 7 weeks of exposure, while a second specimen remains unfailed after testing for 28 weeks. As the strength level of this alloy decreased, the time to failure increased. In distilled water, for example, the failure time at a yield strength of 235,000 psi averaged 4 weeks, and, at 222,500 psi, 20 weeks. At a yield strength of 197,500 psi, the time-to-failure of one specimen was 24 weeks, while a second specimen remained unfailed after 28 weeks of exposure.

2. Type 300M Alloy

Failures of U-bend specimens of Type 300M steel were observed in the environments of distilled water, tap water, marquench salt solution, salt water, and trichloroethylene. At a yield strength of 233,000 psi, for example, failure times averaged 3 weeks for the distilled water and salt water environments, and 4 weeks for the tap water. The only failures observed in the trichloroethylene were at the 213,000 psi strength level after 8 weeks of exposure. One failure was noted in the marquench salt solution, and that occurred at the 233,000 psi strength level after 26 weeks of exposure. A second specimen had not failed after 28 weeks of testing. As with the other alloys, the time-to-failure of this alloy increased as the strength level decreased.

3. Vascojet 1000 Alloy

Failures of U-bend specimens of Vascojet 1000 steel were observed in the environments of distilled water, tap water, salt water, and trichloroethylene. At a strength level of 240,000 psi, for example, failure times averaged 1 week for the distilled water and salt water environments, 2 weeks for the tap water, and 7 weeks for the trichloroethylene. Again, as the strength level of this alloy decreased, the time-to-failure increased.

D. DISCUSSION

As data continue to accumulate, it becomes more apparent that there exists a definite relationship between failure time and environment, alloy, strength level, and stress level. First, certain of the environments were found to be promoters of stress-corrosion cracking, some to a greater degree than others. Other environments did not produce any stress-corrosion cracking whatsoever. Second, three of the six alloys tested were observed to be susceptible to stress-corrosion cracking in the environments investigated. Of these three alloys, Ladish D6AC, Type 300M, and Vascojet 1000 alloy steels, the Vascojet 1000 alloy was found to be the most susceptible to stress-corrosion cracking. No stress-corrosion cracking was observed on any of the other three alloys. Third, the resistance to stress-corrosion cracking of each alloy decreased as the strength level increased. Fourth, failure time decreased as the stress level was increased. All other conditions the same, the U-bend specimens, being at the higher stress level, failed in less time than did the bent-beam specimens.

IV. FUTURE WORK

The following future work is planned:

A. Continuation of the tests already in progress.

B. Completion of the environmental stress-corrosion testing of all the candidate alloys, bonded with solid propellant, at ambient and at elevated temperatures.

C. Environmental stress-corrosion testing of welded bent-beam specimens of Ladish D6AC, Type 300M, and Vascojet 1000 alloy steels, and B120VCA titanium alloy, in distilled water, tap water, salt water, and high humidity.

D. Screening and evaluation of protective coatings for preventing or minimizing stress-corrosion cracking.

TABLE 1

BENT-BEAM STRESS-CORROSI

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	Air: No. Of Specimens	Air: Time To Failure (Days)	Distilled Water: No. Of Specimens	Distilled Water: Time To Failure (Days)	Tap Water: No. Of Specimens	Tap Water: Time To Failure (Days)	0.25% $Na_2Cr_2O_7$ Soln.: No. Of Specimens	0.25% $Na_2Cr_2O_7$ Soln.: Time To Failure (Days)	1% Marquench Salt Soln.: No. Of Specimens	1% Marquench Salt Soln.: Time To Failure (Days)	3% No. Speci
Ladish D6AC	197.5	3	NF-28**	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3
	222.5	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3
	222.5	-	-	-	-	-	-	-	-	-	-	-
	222.5	-	-	-	-	-	-	-	-	-	-	-
	235.0	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3
	235.0	3	NF-149	2	NF-149	6	NF-149	3	NF-104	3	NF-104	3
	235.0	-	-	1	103.8	-	-	-	-	-	-	-
	235.0	-	-	1	125.0	-	-	-	-	-	-	-
	235.0	-	-	1	138.7	-	-	-	-	-	-	-
	235.0	-	-	1	148.7	-	-	-	-	-	-	-
	252.0	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3
	252.0	3	NF-149	2	NF-149	6	NF-149	3	NF-104	3	NF-104	3
	252.0	-	-	1	84.0	-	-	-	-	-	-	-
	252.0	-	-	1	95.8	-	-	-	-	-	-	-
	252.0	-	-	1	113.0	-	-	-	-	-	-	-
	252.0	-	-	1	118.7	-	-	-	-	-	-	-
Type 300M	196.0	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3
	196.0	-	-	-	-	-	-	-	-	-	-	-
	196.0	-	-	-	-	-	-	-	-	-	-	-
	213.0	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3
	213.0	-	-	-	-	-	-	-	-	-	-	-
	213.0	-	-	-	-	-	-	-	-	-	-	-
	233.0	-	-	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3
	233.0	-	-	1	84.0	3	NF-149	-	-	-	-	-
	233.0	-	-	1	112.0	-	-	-	-	-	-	-
	233.0	-	-	1	139.0	-	-	-	-	-	-	-
Vasco-jet 1000	194.0	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3
	212.0	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3
	237.5	3	NF-28	1	7.6	1	13.7	3	NF-21	3	NF-21	1
	237.5	-	-	1	7.8	1	14.7	-	-	-	-	1
	237.5	-	-	1	7.9	1	15.7	-	-	-	-	1
	240.0	3	NF-28	1	1.8	1	2.7	3	NF-21	3	NF-21	1
	240.0	-	-	1	3.2	1	8.8	-	-	-	-	1
	240.0	-	-	1	4.3	1	9.7	-	-	-	-	1
AM355	199.0(T)***	3	NF-49	3	NF-49	3	NF-49	3	NF-49	3	NF-49	3
	250.0(L)	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3
	250.0(L)	-	-	3	NF-149	3	NF-149	-	-	-	-	-
	278.5(L)	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3
	278.5(L)	-	-	3	NF-149	3	NF-149	-	-	-	-	-

*
** Stressed to 75% of the 0.2% offset yield strength.
NF-28 = No failure in 28 days.
*** L = Longitudinal, T = Transverse

TABLE 1

NT-BEAM STRESS-CORROSION TEST DATA*

Environment													
1% Marquench Salt Soln.		3% NaCl Soln.		Trichloroethylene		Cosmoline		4% Soluble Oil Soln.		High Humidity		Solid Propellant	
No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)
3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-181	-	-
3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	1	NF-181	-	-
-	-	-	-	-	-	-	-	-	-	1	57.0	-	-
-	-	-	-	-	-	-	-	-	-	1	61.7	-	-
3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	1	23.0	-	-
3	NF-104	3	NF-104	3	NF-104	3	NF-104	3	NF-104	1	23.2	-	-
-	-	-	-	-	-	-	-	-	-	1	26.7	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	1	5.7	6	NF-15
3	NF-104	3	NF-104	3	NF-104	3	NF-104	3	NF-104	1	7.0	-	-
-	-	-	-	-	-	-	-	-	-	1	14.2	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	1	18.1	-	-
-	-	-	-	-	-	-	-	-	-	1	25.7	-	-
-	-	-	-	-	-	-	-	-	-	1	32.9	-	-
3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	1	3.9	-	-
-	-	-	-	-	-	-	-	-	-	1	6.9	-	-
-	-	-	-	-	-	-	-	-	-	1	19.8	-	-
3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	1	2.7	6	NF-15
-	-	-	-	-	-	-	-	-	-	1	3.9	-	-
-	-	-	-	-	-	-	-	-	-	1	4.8	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	-	-	-	-
3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	-	-	-	-
3	NF-21	1	6.9	3	NF-21	3	NF-21	3	NF-21	-	-	-	-
-	-	1	10.0	-	-	-	-	-	-	-	-	-	-
-	-	1	10.1	-	-	-	-	-	-	-	-	-	-
3	NF-21	1	1.2	3	NF-21	3	NF-21	3	NF-21	-	-	6	NF-15
-	-	1	1.7	-	-	-	-	-	-	-	-	-	-
-	-	1	6.7	-	-	-	-	-	-	-	-	-	-
3	NF-49	3	NF-49	3	NF-49	3	NF-49	3	NF-49	-	-	-	-
3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-43	6	NF-22
-	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 1 (Cont.)

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	Air		Distilled Water		Tap Water		0.25% $Na_2Cr_2O_7$ Soln.		1% Marquench Salt Soln.		3% NaCl
		No. Of Specimens	Time To Failure (Days)	No. of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens
PH 15-7 Mo	199.5	3	NF-149	3	NF-109	3	NF-109	3	NF-109	3	NF-109	3
	225.0	3	NF-149	3	NF-109	3	NF-109	3	NF-109	3	NF-109	3
	237.0	3	NF-149	3	NF-109	3	NF-109	3	NF-109	3	NF-109	3
B120VCA Titanium	137.5(L)	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3
	139.5(T)	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	1
	139.5(T)	-	-	-	-	-	-	-	-	-	-	1
	139.5(T)	-	-	-	-	-	-	-	-	-	-	1
	145.5(T)	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3
	145.5(T)	-	-	-	-	-	-	-	-	-	-	-
	149.0(L)	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3
	158.0(L)	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3
	166.0(T)	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3
	166.0(T)	-	-	3	NF-149	3	NF-149	-	-	-	-	-

TABLE 1 (Cont.)

Environment													
1% Marquench Salt Soln.		3% NaCl Soln.		Trichloroethylene		Cosmoline		4% Soluble Oil Soln.		High Humidity		Solid Propellant	
No. Of pecimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)
3	NF-109	3	NF-109	3	NF-109	3	NF-109	3	NF-109	3	NF-112	-	-
3	NF-109	3	NF-109	3	NF-109	3	NF-109	3	NF-109	3	NF-112	-	-
3	NF-109	3	NF-109	3	NF-109	3	NF-109	3	NF-109	3	NF-112	6	NF-22
3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	-	-	-	-
3	NF-21	1	NF-21	2	NF-21	3	NF-21	3	NF-21	-	-	-	-
-	-	1	0.0+	1	3.4	-	-	-	-	-	-	-	-
-	-	1	0.03	-	-	-	-	-	-	-	-	-	-
3	NF-21	3	NF-21	2	NF-21	3	NF-21	3	NF-21	-	-	-	-
-	-	-	-	1	0.9	-	-	-	-	-	-	-	-
3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	-	-	-	-
3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	-	-	6	NF-22
3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	-	-	6	NF-22
-	-	-	-	-	-	-	-	-	-	-	-	-	-

2

TABLE 2

U-BEND STRESS-CORROSION TEST

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	Environ: Distilled Water No. Of Specimens	Distilled Water Time To Failure (Days)	Tap Water No. Of Specimens	Tap Water Time To Failure (Days)	0.25% $Na_2Cr_2O_7$ Soln. No. Of Specimens	0.25% $Na_2Cr_2O_7$ Soln. Time To Failure (Days)	1% Marquench Salt Soln. No. Of Specimens	1% Marquench Salt Soln. Time To Failure (Days)
Ladish D6AC	197.5	1	NF-198*	2	NF-198	2	NF-198	2	NF-198
	197.5	1	167.6	-	-	-	-	-	-
	222.5	1	137.3	2	NF-198	2	NF-198	2	NF-198
	222.5	1	141.7	-	-	-	-	-	-
	235.0	1	20.2	1	33.3	1	NF-198	2	NF-198
	235.0	1	32.9	1	189.6	-	-	-	-
	252.0	1	18.4	1	28.9	2	NF-198	2	NF-198
	252.0	1	22.4	1	39.9	-	-	-	-
Type 300M	196.0	1	111.7	2	NF-198	2	NF-198	2	NF-198
	196.0	1	193.5	-	-	-	-	-	-
	213.0	1	18.4	2	NF-198	2	NF-198	2	NF-198
	213.0	1	34.9	-	-	-	-	-	-
	233.0	1	14.9	1	22.4	2	NF-198	1	NF-198
	233.0	1	34.9	1	29.1	-	-	1	182.7
Vasco-jet 1000	194.0	1	140.7	1	140.7	2	NF-198	2	NF-198
	194.0	1	181.5	1	163.4	-	-	-	-
	212.0	1	14.7	1	60.4	2	NF-198	2	NF-198
	212.0	1	141.7	1	69.4	-	-	-	-
	240.0	1	4.4	1	7.4	2	NF-198	2	NF-198
	240.0	1	11.4	1	19.5	-	-	-	-

*NF-198 = No Failure in 198 days.

1

TABLE 2

U-BEND STRESS-CORROSION TEST DATA

2

Environment												
0.25% $Na_2Cr_2O_7$ Soln.			1% Marquench Salt Soln.		3% NaCl Soln.		Trichloroethylene		Cosmoline		4% Soluble Oil Soln.	
)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Fail ure (Days)	No. Of Specimens	Time To Failure (Days)
3	2	NF-198	2	NF-198	2	NF-198	2	NF-198	2	NF-198	2	NF-198
	-	-	-	-	-	-	-	-	-	-	-	-
3	2	NF-198	2	NF-198	2	NF-198	2	NF-198	2	NF-198	2	NF-198
	-	-	-	-	-	-	-	-	-	-	-	-
	1	NF-198	2	NF-198	1	62.4	2	NF-198	2	NF-198	2	NF-198
	-	-	-	-	1	116.3	-	-	-	-	-	-
	2	NF-198	2	NF-198	1	18.5	1	NF-198	2	NF-198	2	NF-198
	-	-	-	-	-	-	1	46.9	-	-	-	-
8	2	NF-198	2	NF-198	1	NF-198	2	NF-198	2	NF-198	2	NF-198
	-	-	-	-	1	149.4	-	-	-	-	-	-
8	2	NF-198	2	NF-198	1	11.3	1	49.9	2	NF-198	2	NF-198
	-	-	-	-	1	40.9	1	56.1	-	-	-	-
.	2	NF-198	1	NF-198	1	11.3	2	NF-198	2	NF-198	2	NF-198
.	-	-	1	182.7	1	26.3	-	-	-	-	-	-
'	2	NF-198	2	NF-198	1	NF-198	2	NF-198	2	NF-198	2	NF-198
+	-	-	-	-	1	49.9	-	-	-	-	-	-
+	2	NF-198	2	NF-198	1	13.7	2	NF-198	2	NF-198	2	NF-198
+	-	-	-	-	1	53.3	-	-	-	-	-	-
+	2	NF-198	2	NF-198	1	4.3	1	46.9	2	NF-198	2	NF-198
;	-	-	-	-	1	6.8	1	46.9	-	-	-	-

Bent-Beam Specimen Failures

Figure 1

U-Bend Specimen Failures

Figure 2